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# THEORY OF GEODYNAMO AND SECULAR VARIATIONS

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According to the goal of the proposal, geodynamo theory and the theory of secular variations (SV) have been investigated. Both topics were significantly advanced and new ideas were put forward that we hope will make it possible to overcome some long standing difficulties of the theory of the Earth's magnetism.

During the first two years the Co-PI worked mainly on the physical mechanisms of the SV trying to derive the consequences of the assumption that a special, strongly stratified, thin layer exists on the core mantle boundary. In this case the widely used "frozen flux approximation" (assumption of infinite core conductivity) turns to be invalid. To investigate some limitations of the frozen flux approximation a simple "kinematic" model was developed that includes a thin layer of high horizontal velocity near the CMB and takes into account the finite conductivity of the core. This work (undertaken together with Prof. J. L. Le Mouël, Institute de Physique du Globe de Paris) displays very interesting features, such as an intense horizontal field "hidden" in the thin layer. This kinematic approach is intrinsically ambiguous, and a more fundamental "dynamic" approach is necessary which is much more complicated. The dynamic approach includes the investigation of the motions and magnetic fields in a stably stratified layer near the CMB. The existence of this layer was suggested by the Co-PI in 1984, because of the difficulty in explaining the decadal SV of the geomagnetic field and the length of day (l.o.d.), for which oscillations with a period of about 65 y were detected. The investigation of this layer was undertaken by CoPI using the complete system of equations describing the dynamics of the layer. It was shown that global axisymmetric eigen-oscillations of the layer are possible that are similar to MAC-waves. These oscillations have periods of the order of 65 y if $N \sim 2\Omega$, where N is the Brunt-Väisälä frequency of the layer and $\Omega$ is the frequency of the Earth's daily rotation. This relation is characteristic for systems, like the Earth's atmosphere and oceans, where dynamics are determined by the interplay between Coriolis and Archimedean (buoyancy) forces. That is why we christened this layer the "Hidden Ocean of the Core" (HOC).

It was shown by CoPI in 1970 that torsional oscillations (TO) are possible in the bulk of the core but their source was obscure then. Motions in the HOC are coupled to the torsional oscillations according to the theory of the HOC. The oscillations of the HOC can be excited by an instability mechanism that resembles baroclinic (sloping) instability, and they in turn can excite the TO. A rough estimate of the physical parameters of the HOC was obtained by comparison of the developed theory of the HOC-oscillations with the observed geomagnetic and length of day decadal variations. This estimate gives $N \approx 2\Omega$ and a layer thickness of $H \approx 80$ km. The HOC parameters were therefore, for the first time, estimated from the observational data. The joint action of HOC and TO oscillations provides a long sought mechanism for the generation of the decadal geomagnetic secular variations, and the associated variations in the length of day. This opens the way for the creation of a realistic theory of decadal geomagnetic and l.o.d. variations.

The second half of the grant period was devoted to the development of the geodynamo theory. We investigated the relation between Taylor type and model-Z type behavior of intermediate dynamo models by means of a rather massive numerical calculations. The parameters of the model were broadly varied so that about two hundred model solutions were obtained which lead to following results. When a dynamo is near its marginal state, it may well be of Taylor type, with a form almost unaffected by core-mantle coupling, but as intensity of sources increases ( the dynamo number becomes larger) it increasingly becomes of model-Z type i.e. core mantle coupling, though very weak, becomes crucial.

Massive numerical calculations of the geodynamo are now being undertaking by a few scientific groups around the world, most of them based on the Boussinesq approximation, whose validity is not obvious for the conditions of the Earth core. We reconsidered and derived from first principles the governing equations of the magnetohydrodynamics of the core considered as a binary alloy of iron and some light admixture. This resulted in a sequence of three mathematical models of increasing simplicity: (1) the inhomogeneous model based on the anelastic approximation, (2) the modified Boussinesq approximation, and (3) the compositional model artificially simplified by neglecting thermal convection.

We succeeded in finding a new powerful simplification of the anelastic equation governing the fluid motion. The important role of small-scale motions was recognized through the introduction of a local turbulence model, and the proper averaging of the whole set of equations over the turbulence was performed using some model simplifications. The numerical values of relevant physical parameters of the Earth core were reevaluated, and most significant uncertainties were highlighted. A new criterion was advanced which can be used to discriminate between different possible candidates for the admixture in the core (S, Si, O) once the phase diagram of the relevant alloy under high pressure becomes better known. For the present we prefer S or Si to O. The energetics of core convection and the geodynamo were reconsidered. We obtained a new expression for the efficiency of the geodynamo, considered as a heat engine, and came to the conclusion that both thermal and compositional sources are significant for driving the geodynamo. This work laid a proper foundation for studying core convection and the geodynamo, and we hope that it will be broadly used in geophysical studies.

The PI and the CoPI gave lectures on the basis of dynamo theory and on the model-Z dynamo at the NATO Advanced Study Institute held in 1992 in Cambridge, UK, and published them as review papers. The discussion of problems raised by the dual (thermal and compositional) nature of core convection influenced by the core turbulence was presented by CoPI at the Conference on MHD Stability and Dynamos in Chicago, 1992, under the title "The Role of the Turbulent Diffusivity in the Geodynamo Mechanism." Results connected with the theory of HOC were presented on the SEDI meeting in Mizusawa, Japan, 1992; results connected with the model-Z theory and the main results of our paper about fundamentals of core convection and geodynamo were presented on the SEDI meeting in Whistler, Canada, 1994.

No patents or inventions resulted from this effort.

Published papers supported by this grant:

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